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Blasting with Solid Carbon Dioxide – Investigation of Thermal and Mechanical Removal Mechanisms

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Abstract

Cleaning technology is an important factor in the field of production technology as well as service and recycling. Blasting with solid carbon dioxide (dry ice blasting – dib) is generally based on compressed air, which is a flexible but energy consuming acceleration method. To improve the mechanical acceleration by rotational wheel blasting, the main removal mechanisms of dib, mechanical and thermal, have been investigated separately. Based on the developed methods both mechanisms can be characterized independently of the target type. The presented results show a promising approach to determine the size of the mechanical removal mechanism's impact force. Obviously it depends primarily on the blasting pressure, one of the main influencing process factors.

Cleaning applications – substrate and the adherence of the residues – show different resistance against thermal stress as well as against mechanical impact. Because of this, an overall benchmark independently of the application had to be defined in order to compare the blasting efficiency of both blasting technologies and the results.

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Keywords: Blasting Technology; Energy Efficiency; Impact Mechanisms; Impact Force Measurment

1. Introduction Main text

In the context of surface technology great importance is attached to the cleaning and maintenance of metalworking machines [1]. Cleaning is the removal of residual lubricants, process liquids as well as remaining substances from preceding processes. Total removal of cooling lubricant residuals and chips is usually done by an aqueous or organic rinsing medium. For the transfer of the contamination into this cleaning medium and the following lubricant regeneration as well as the lubrication process itself, a significant amount of energy is required, e.g. for the heating or vacuum generation [2]. The cleaning process can make a substantial part of specific manufacturing chains: For example, up to 25% of production time and of production costs are generated by purification processes within the manufacturing chains of representative automobile parts [3]. Flexibility in the design/application of cleaning technologies is important due to the continuously changing requirements of different cleaning tasks [4].

2. Cleaning Applications

The suitability of dry ice blasting (dib) for cleaning and pre-treating was confirmed in detailed experiments [5, 6]. In the area of selective cleaning by means of dry ice blasting several applications had already been investigated: Examples are the combination of cleaning mechanisms, the decrease of noise emission, the increase of the material removal rate through hybrid combinations as well as energy efficient alternative acceleration concepts [7, 8].

Dry ice based cleaning technology can help to avoid down-times regarding current carrying power plant installations. For the inline cleaning of wood machining tools blasting with solid carbon dioxide (CO_2) offers a task oriented selective cleaning technology. The prerequisite for the process

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integration of cleaning by compressed air driven dry ice blasting is a substantial decrease of the noise level of up to 120 dB(A). Therefore, approaches of noise reduction regarding various noise emergences were studied to develop noise reducing nozzles. As an energy efficient alternative to compressed air driven processes the mechanical acceleration of the dry ice pellets was examined with the help of a centrifugal wheel blasting device.

3. Blasting with solid Carbon Dioxide

Dry ice blasting has been intensively investigated [9]. Solid carbon dioxide (CO_2) is a one-way blasting medium. Due to sublimation, no additional solid residues of the blasting medium remain beside the removed contaminant. CO_2 is chemically inert. In solid state the hardness of dry ice pellets is comparable with gypsum and the temperature at ambient pressure is -78.5°C. Recent investigations of the hardness came to the result of a Mohs hardness of 1.5 [3]. The CO_2 used as blasting media does not contribute to global warming, since it is either a by-product of the chemical industry or derived from natural sources [7]. In any case the CO2 – if used as blasting media or not – gets nevertheless into the atmosphere.

Two forms of blasting with solid CO_2 have to be distinguished: CO_2-snow blasting and dry ice pellet blasting. Beyond this the acceleration method, either by compressed air or mechanical by rotational wheel blasting, influences the energy efficiency as well as the blasting foot print.

The CO_2-pellets are made of CO_2-snow, which is pressed through a matrix. The diameter of the matrix' holes as well as the environmental conditions determine the properties of the CO_2-pellets, the so-called dry ice.

The cleaning effect of solid CO_2 blasting is based on a combination of a mechanic and a thermal mechanism (**Fehler! Verweisquelle konnte nicht gefunden werden.**), which is supported by the sublimation of the blasting media. While the contaminant is mechanically removed by the impact of the CO_2 particles (A), tensions at the interface of the contaminant and the surface to be cleaned are a result of the thermal mechanism (B). Due to the sublimation the surface is additionally cooled, which increases the thermal mechanism.

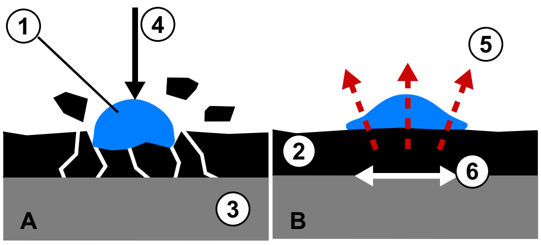


Fig. 1: Thermal (A) and mechanical (B) removal mechanisms

3.1. Motivation

Nevertheless, essential questions still have to be answered for a significant better understanding and a potential improvement of the blasting process. In particular the direct energy consumption for the majority of the purification processes is to be reduced. The Identification of the relevant mechanisms for the cleaning, e. g. mechanical and/or thermal is needed for their detailed investigation. Can these be separated and recombined for a specific cleaning task more effectively?

To identify the primary removal mechanism of a specific cleaning task, the different mechanisms have to be varied. Up to now, various investigations were conducted, but a measurement of the effects proved to be difficult. Due to the sublimation of the dry ice pellets as well as of the blasted CO_2-particles a measurement of their properties is not possible with conventional methods. But the solid CO_2's hardness, impact force and cooling effect is of interest with regard to the residue's removal and the cleaning process. The contact time of the particle's impact onto the workpiece (or any sensor) is of high significance for the measurement.

3.2. State of the art

UHLMANN investigated the impact force of blasted CO_2-pellets. Besides the indirect effects generated on the so-called blasting good the blasted particle's velocity was measured and the resulting kinetic energy calculated. The impact force was measurement by piezo-electric load cell. He distinguished a static and a dynamic force component. The dynamic force of dib was measured to be approx. four times as high as compressed air blasting for specific parameter settings. In opposite the static component of dib was only 10% higher than compressed air blasting. The maximum impact force measured is of higher relevance for the particle's impact: Dry ice blasting resulted in 150 N, compressed air blasting in 75 N [10].

HABERLAND investigated the removal effects, too. By the application of thermocouples the cooling of the workpiece was documented. Due to the already cooled compressed air (down to approx. -70° C), which accelerated the pellets and the workpiece specific heat conduction the minimum temperature was already reached before an initial pellet impact. The impact was observed by a high speed camera (hsc). Because the pellet was entirely smashed he calculated a contact time by the particle's velocity and dimensions of approx. 22 µs. Additional he supposed a possibly melting by the impact observation [11].

REDEKER formed a lager carbon dioxide cylinder and measured the properties with conventional but cooled equipment. By the help of the measured elastic modulus a contact time of approx. 1.5 µs to 50 µs for the elastic impact was calculated. The values depended only on the particles' diameter between 0.1 mm and 3 mm. Regarding the solid carbon dioxide's hardness and flow limit a total elastic impact is unlikely. In a plastically approach, REDEKER assumes a contact time of less than 15 µs to 500 µs. Though being much longer than it can be observed by many investigations by hsc he concluded, that this is still too short for the significant thermal effect supposed by others [12].

KRIEG investigated the mechanisms and their total proportion of the removal rate. He believed to prove the existence of the particles' sublimation at the impact because of lower temperatures than the temperature of the gaseous-solid phase equilibrium at an ambient pressure (of CO_2). A removal effect due to the sublimation's expansion could not be measured by the help of a piezo-electric load cell. The measurement of the impact force by the same piezo-electric load cell failed, too: In opposite to the results of UHLMANN mentioned above the blasting force of compressed air measured by KRIEG was higher than of dry ice blasting [13].

Previous research investigated in particular the effects of dry ice blasting on the workpiece and workpiece material. The CO_2-particle itself was rarely in the focus. Furthermore, literature shows partially contradictory results and assumptions with regard to the removal effects and their contribution to the total material removal.

3.3. Outline

The air jet of conventional dry ice blasting is influencing the measurement of the impact force and the temperature on the workpiece. Though the impact of the dib force was measured, the contribution of the air jet by the compressed air (to accelerate a potential blasting media) is unknown. Regarding the maximum impact force measured by UHLMANN it is vague if the air jet force has to be subtracted or not: The particle impact might happened at a maximum or minimum of the air jet force. KRIEG's investigations even showed an opposite result.

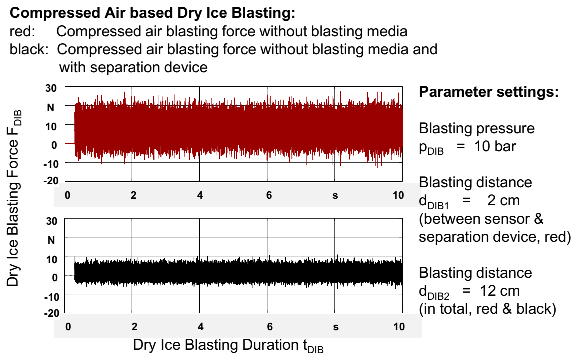
Because of the short contact time of a CO_2-pellet impact the process has to be observed by a high speed camera. This requires adequate frame rates of approx. 10^6 s^{-1} to gain new insights of the process. Up to now a high speed camera is obviously the only possibility to investigate such short contact times as mentioned above. The contact time of the impact must be taken into consideration for any sensor's result.

To improve the blasting process by separating and recombining the removal mechanisms application specific, the effects have to become measurable. This will help to improve the mechanical acceleration of non-durable blasting media like solid CO_2 by rotational wheel blasting, which offers significant higher energy efficiency. The losses to early sublimation could be significantly reduced by identifying a maximum load, impact or down force a dry ice particle can take during acceleration without disruption. Due to this the impact force of compressed air based dib is investigated first. A first step is to reduce or quantify the influence of the air jet. Regarding the physical quantity adequate sensors have to be provided. In addition a parallel high speed camera observation has to be combined with the data to gain additional information.

4. Investigation of the mechanical removal mechanism

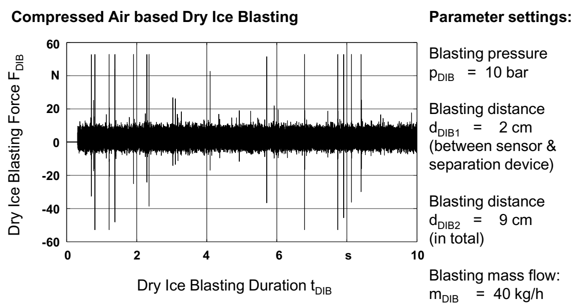
The process force orthogonal to the workpiece is influenced by the air jet of compressed air based acceleration of any blasting media. Additionally the air jet is cooling the blasting spot thus influencing any sensor to measure the main removal mechanisms [11]. Because of this a separation device was developed, which reduces the influence of the air jet significantly. Figure 2 shows the reduction of blasting force of approx. 60 %.

Fig. 2: Air jet blasting force of compressed air blasting; without and with a developed separation device



In addition only the impact of selected particles could be observed. This offers the possibility to examine particles of the conventional blasting process. REDEKER investigated single particle impacts accelerated by a single-particle blasting device. A deviation to the common blasting process regarding its representativeness was not discussed. Figure 3 shows the measured impact force of selected CO_2 particles. The relation of the maximum impact signal and the background signal of the air jet is approx. 5:1.

Fig. 3: Impact force of single particle impacts and background force of the air jet



Before the obtained date can be analyzed, a reference is needed for the sensor's signal. This applies to the sensor's value as well as to the signal's frequency. Though the impact and the air jet result only in positive values, the sensor shows an oscillation and resulting in negative values, too. The high frequency turbulence of the air jet and in particular the short contact time of the particle impacts in comparison to the sensors own frequency are supposed to be the reason. A single particle impact of the dry ice blasting is shown in Fig. 4 (top). A standardized impact of a ceramic ball is shown in Fig. 4 (bottom) to be used as a reference.

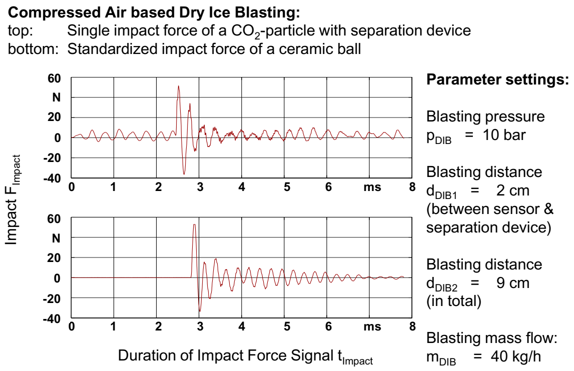


Fig. 4: Single CO_2-particle impact (top) and standardized impact of a ceramic ball for comparison

5. Results

The developed separation device enables to analyze the impact force of the dry ice particles and the air jet force separately. The ratio of 5:1 is higher in comparison to former investigations of the impact force. Up to approx. 50 N of single impact forces of solid CO_2-particles' signals have been observed. Former investigations showed higher maximum values at more aggressive blasting parameter settings, higher blasting pressure in particular. In general, all tests resulted in higher maximum impact forces of dry ice blasting than single compressed air blasting at the same parameter settings.

6. Conclusions and outlook

The duration of the contact of a solid CO_2-particle is of high relevance. Besides a highest possible own frequency of any sensor the necessarily high sample rate of the data logger has to be met. The latter allows at least to identify the impacts though the impact signal's value still has to be processed carefully. They have to be verified by additional process data gained by sensors with the higher total sample rate compared to the contact time of a particle's impact. This is part of the work in progress.

It is intended to use a high speed camera for a simultaneously observation. The measured contact duration of a CO2-particle's impact in comparison to a standardized ceramic ball impact's contact duration will help to use the impact force signal's value. Thus a quantification of the impact force could help to set up a relation of the particle's velocity, impact force and its resulting disruption.

Furthermore the thermal effect will be analyzed systematically. A measurement method for the heat transfer and the resulting cooling effect has to be set up. A possibly interrelation of impact force and cooling effect has to be investigated for the separation and recombination approach mentioned at the beginning.

The development of the separation device is part of the same PhD-thesis as the fundamental investigation of the impact force. Nevertheless, the idea will be pursued separately to realize the blasting effect without an air jet at the blasting focus.

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